Integrated water resources management in the Loukkos basin (Morocco): an approach to improve resilience under climate change impact

Gestion intégrée des ressources en eau dans le bassin du Loukkos (Maroc) : une approche pour améliorer la résilience face aux impacts du changement climatique

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Abstract. The Loukkos basin located in northern Morocco is characterized by developed agriculture and a significant water demand. The water needs are mainly satisfied from the Oued El Makhazine dam on Loukkos River. This dam is impacted by the silting up of its reservoir and by the large amount of not valued water discharged into the sea. The aim of this study is to develop an approach to secure water supply and promote an optimal use of basin water resources, using the decision-making tool RIBASIM. The study includes an assessment of the hydraulic performances of the current situation and an analysis of two scenarios by the 2050 horizon that are tested under climate change impacts. The analysis of the first scenario without actions shows an average deficit of 20 million cubic meters (MCM). The second scenario including the new dam shows an increase in the regularised volume by 20% and the water resource meet fully the water needs. However, they remain vulnerable to the climate change impacts, and imply that certain measures have to be undertaken. This article presents one of these measures, which consists of developing an approach to interconnect existing dams in the Loukkos basin. Keywords: RIBASIM, water management, climate change, Simulation, Loukkos.

Résumé. Le bassin de Loukkos, situé au nord du Maroc, se caractérise par une agriculture développée et une demande en eau importante. Les besoins en eau sont principalement satisfaits à partir du barrage d'Oued El

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Makhazine sur Oued Loukkos. Ce barrage est impacté par l'envasement et par la grande quantité d'eau non valorisée déversée en mer. Le but de cette étude est de développer une approche pour sécuriser l'approvisionnement en eau et favoriser une utilisation optimale des ressources en eau du bassin, en utilisant l'outil d'aide à la décision RIBASIM. L'étude comprend une évaluation des performances hydrauliques de la situation actuelle et une analyse de deux scénarios à l'horizon 2050 qui sont testés sous l'effet du changement climatique. L'analyse du premier scénario sans actions montre un déficit moyen de 20 millions de mètres cubes (MCM). Le second scénario incluant le nouveau barrage montre une augmentation du volume régularisé de 20 % et la ressource en eau répond pleinement aux besoins en eau. Cependant, ils restent vulnérables aux impacts du changement climatique et impliquent la prise de certaines mesures. Cet article présente l'une d'elle consistant à développer une approche d'interconnexion des barrages existants dans le bassin de Loukkos. Mots clés : RIBASIM, gestion de l'eau, changement climatique, simulation, Loukkos.

1 Introduction

The dams have played and are still playing an important role in water management, especially for areas with irregular rainfall and limited water availability. In the world, we count more than 57.000 large dams according to the International commission on large dams (ICOLD) [1-2].

Initially, the dams were built to ensure water security especially drinking water and irrigation. Currently with socio-economic growth and civilization, dams are also used for flood control, energy production, environmental protection, fish farming, water intake, regulation, water reserve against fires, site historical and other uses [1]. The importance of dams is strongly coupled to several aspects other than population growth and water demand, such as economic development [3] and climate change [4].

Since its independence, and to cope with irregular water supplies in space and time, Morocco has pursued a policy of dams in the 1960s, to ensure the country's water security and which has enabled a relatively efficient mobilization of surface and underground resources. Dams are still being built to this day to cope with the constraint of growing water demand, and strategies are being developed to support and catch up with the country's economic, social and climatic changes.

According to the Moroccan Water Department, Morocco today has 146 large dams with a total storage capacity estimated at 19.1 billion cubic meters, and 14 other dams under construction with a total storage capacity of 2.9 billion cubic meters, which will bring the storage capacity to 22 billion cubic meters. In addition to this, there are other hydraulic infrastructures, whether for wastewater reuse, seawater desalination and water distribution and transport canals [17-18].

These achievements has allowed the generalization of access to drinking water, the development of irrigation of nearly 2 million ha, the production of hydroelectric power and the protection against flooding of several sites.

The integrated water resources management (IWRM) in Morocco is becoming a fundamental socio-economic issue as climatic variability and change increase and the high pressure of water demand on resources, and as Animesh K. and al concluded, « All the key dimensions of IWRM promote adequate supply of resources and facilitate participatory mechanisms, which can enhance adaptive capacity ». (6) IWRM, as defined by the Global Water Partnership [5], is a process that encourages the development and coordinated management of water, land and associated resources with a view to maximizing the resulting economic and social well-being in an equitable manner without compromising the sustainability of vital ecosystems [7].

In addition, the significant pressures on water resources coupled to climate change and water use require adaptation of water resource management. Therefore, it is necessary to develop an integrated and interdisciplinary approach, which makes it possible to assess the impact of climate change and water uses on the capacity of resources to meet demand.

Indeed, the use of modelling has become a fundamental approach to evaluate water resources management policies. In this context, several research works have developed decision-support tools, which make it possible to determine the water supply, to estimate the evolution of water demands and to apply evolution scenarios in order to assess meeting needs in the future, as WEAP model [8-10], Mike Bassin [12-11], Ribasim [13-15], Modcel [16].

The main objective of this paper is to examine the role of modelling for efficient water resource management of the Loukkos basin and the potential impact of a reduction of upstream dam flow in the allocation of water for domestic and irrigation uses. This evaluation will take into account the climate change impact and it would be made using the software RIBASIM (RIver BAsin SIMulation).

2 Method

The present work focuses on the integrated water resources management and planning of the Loukkos basin in a context of climate change, to ensure the public water supply and irrigation needs for long term (2050), and reduce dam spilling during the wet period. For this study, a numerical model of the Loukkos basin was developed to define and evaluate water resources management policies that can ensure the sustainable development of this basin. This assessment allows decision-makers to determine and implement actions to minimize water shortages and secure public water supply and agricultural demand in the medium and long term.

The used approach includes the development and analysis of different scenarios taking into account existing and planned dams with the integration of climate change effect (fig. 1).

The development of these scenarios is based on the analysis of the current situation and the comparison between various existing alternatives.

The Loukkos basin water resources planning tool is developed using the "RIBASIM" decision support tool.

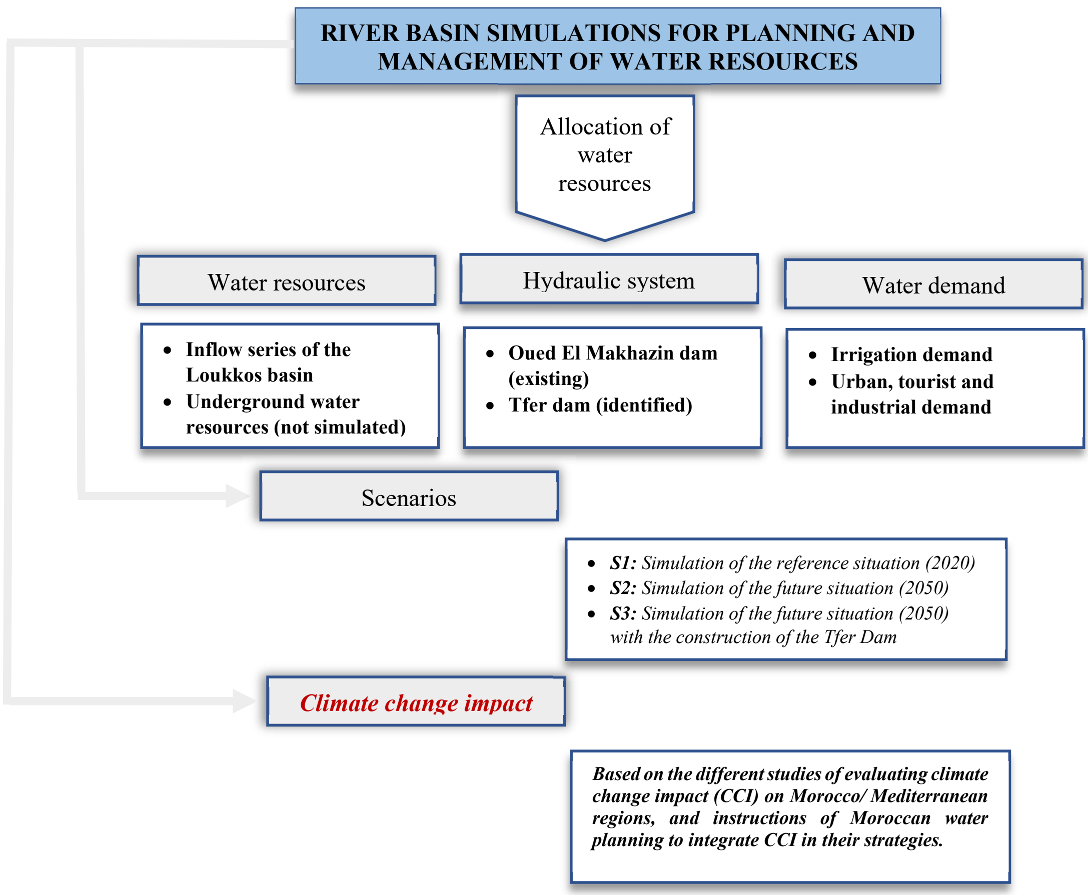


Fig. 1: Water Resources Management and Planning Framework.

2.1 Description of the model

River Basin Simulations, developed by "Delft Hydraulics" in Holland, is a set of models for planning and management of water resources at watershed level [19]. The model compares water supply with current and future demands at different horizons and with different scenarios.

RIBASIM simulates all the behaviors of the hydraulic basins under different hydrological conditions. By changing the inputs of the studied system, different water balances are generated. The evaluation of the hydraulic balances, conclusions and recommendations came out and that should support policy makers.

This model is one of the most used by Moroccan planners, which gives the user a better visibility on the different elements composing a hydraulic model, which makes it a very powerful decision support tool.

The main function used by RIBASIM to assess the variation in stock at Oued El Makhazine dam is the hydraulic balance equation:

$$\Delta V = VE - VS - EN \times S \times 10^{-6} \tag{1}$$

Where:

ΔV: The change in stock in (MCM).
VE: The volume of natural input evaluated at the dam site in (MCM).
VS: The volume of releases in (MCM).
EN: The net evaporation rate in (mm).
S: The average surface area of the reservoir in (km^2).

2.2 Study area and data

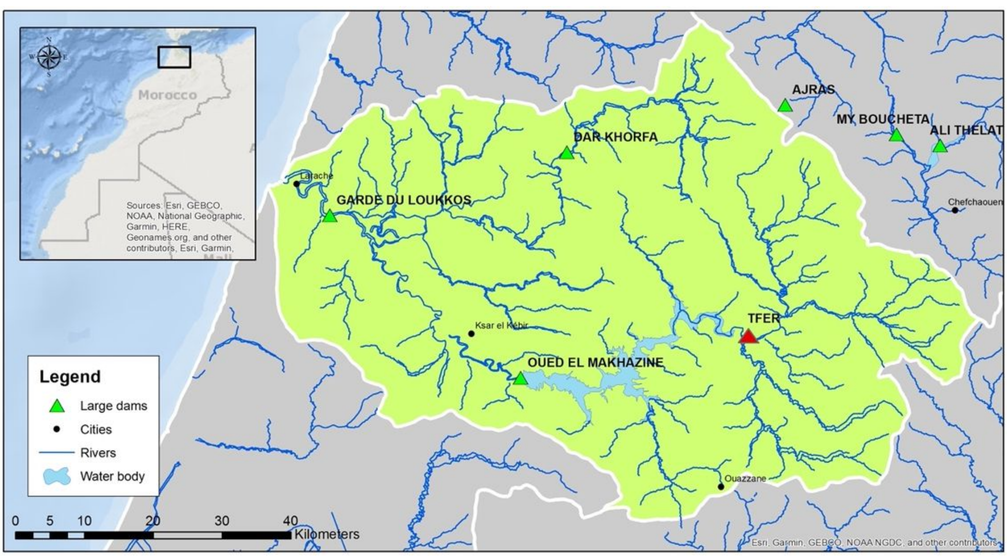
2.2.1 Study area

The study area concerns Loukkos Basin, located in northern Morocco, and covers an area of 4,771 km^2. The basin has significant potential of surface water resources with an average inflow of 1200 million cubic meters per year. The basin supplies water through Oued El Makhazine dam, built in 1979, with an actual storage capacity of 673 MCM, which allows irrigation, public water supply, energy production, as well as protection against flooding. (fig.2)

The climate is semi-humid with an average annual temperatures vary between 14ºC and 20ºC with a minimum in December-January and a maximum in July-August.

The area has significant economic assets, which have enabled it to relaunch its economic and social development and to contribute to the fight against social and regional disparities. These potentialities are perceptible through an increasingly modern agriculture, an industry in constant evolution and diversified tourism.

Fig. 2: Location of the study area.



2.2.2 Data

- The simulations concern the evaluation of two horizons 2020 and 2050, with considering the inflow recorded at the Oued El Makhazine dam over the period 1945-2017. The characteristics of the simulated dams are as follows:

Table 1. Dams characteristics.

Characteristics	Inflow (MCM /y)	Reservoir level (mNGM)	Capacity 2020 (MCM)	Objective
Oued El Makhazine	731	61.5	673	Public water supply, irrigation, flood protection and energy production
Tfer	678	105	885	Public water supply and irrigation

- The level of the dead storage is linked to the siltation rate at the horizon of simulation. The water releases (discharges and water supplies) are carried out according to the dead storage level in the dam reservoir through the main gate. The assumptions taken into account are presented in the table below.

Table 2. Main gate setting dimension according the dead storage.

Dams	Oued El Makhazine	Tfer
Siltation rate (MCM/y)	3.9	3.9
Dead Storage volume 2020 (MCM)	27.6	-
Dead Storage volume 2050 (MCM)	144.3	-
Dead storage level 2020 (mNGM)	29.8	-
Dead storage level 2050 (mNGM)	41,3	63

- The evaporation recorded at the Oued El Makhazine dam is around of 920 mm/y. Given the context of the basin, evaporation at the Tfer dam is taken equal to that of the Oued El Makhazine dam.
- The expressed water demands are collected from the National Office of Public Water and the Department of Irrigation Services. The demand and its modulation are presented in Fig.3:

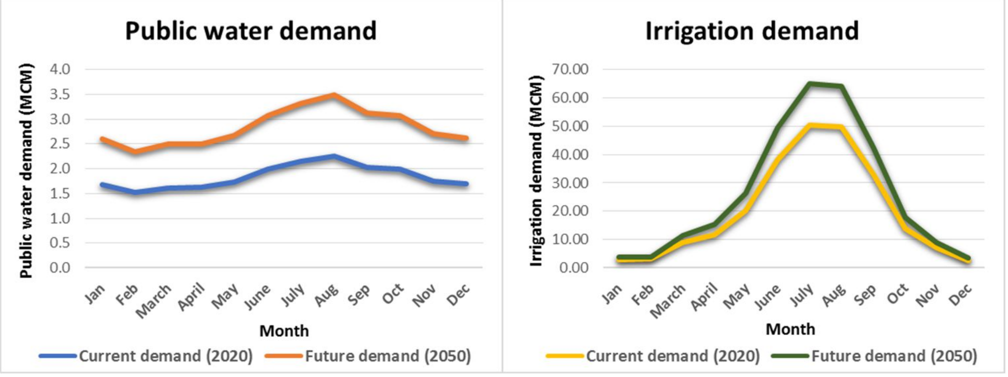


Fig. 3: Modulations of public water and irrigation demand.

- **Supply guarantee criteria**

The potential of the resource, expressed in volume of regulated water, depends not only on hydraulic inputs and the physical possibilities of its regulation through hydraulic structures, but also on the guarantee conditions that are required when the resource is called.

The tolerance threshold of a water resource deficit, which cannot be constant, is a determining criterion, which depends fundamentally on the flexibility of the consumer.

The supply guarantee criteria to be respected during the simulation by sector are:

- Public Water Supply:
  - Any year in which the annual deficit exceeds 0% of the total annual need for water public supply (PWS) is considered as a year in deficit
  - Max deficit per year: 0%
  - Failure frequency: 0%
- Irrigation:
  - Any year in which the annual deficit exceeds 15% of the total annual need for irrigation water is considered a year in deficit
  - Max deficit per year: 50%
  - Failure frequency: 20% (2/10 years)

- **Scenarios**

The approach followed in this study concerns carrying out simulations according to three main scenarios:

1. **Scenario I (S1):** Reference situation (2020)
2. **Scenario II (S2):** Future situation by 2050

   S2.1: Without climate change impact

   S2.2: with climate change impact
3. **Scenario III (S3):** Future situation by 2050 with the construction of Tfer dam upstream of the Oued El Makhazine dam

   S3.1: Without the effect of climate change

   S3.2: with climate change Impact

- **The schematization**

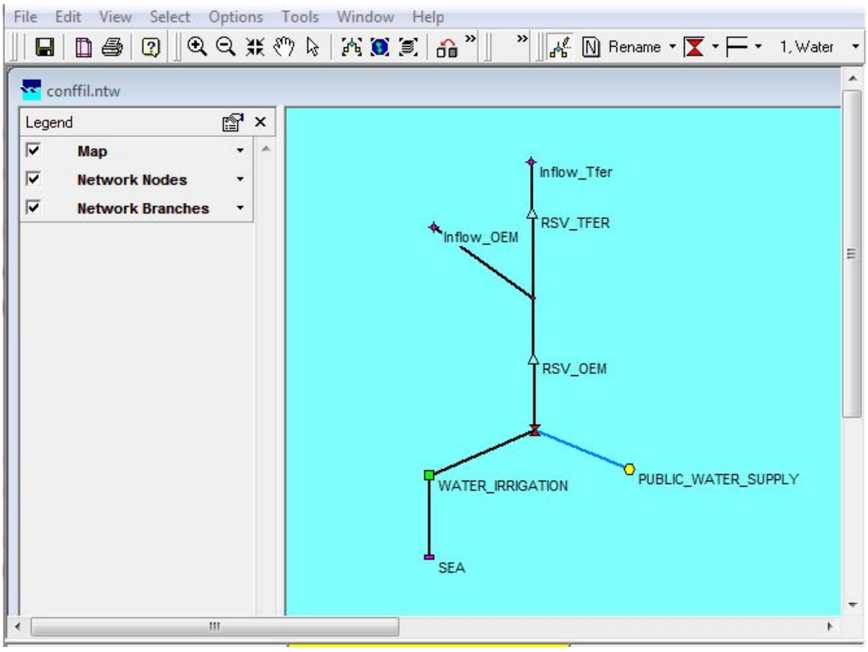


Fig. 4: Schematization of the existing and the future reservoirs and water users in RIBASIM software.

2.3 Climate impact assessment

2.3.1 Observed trends

Over the past five decades, Morocco's climate has experienced widespread temperature increases in all seasons and changes in annual rainfall amounts varying by region. According to Schleussner and al. (2016) [20], the reduction in water resources in the Mediterranean region would drop from 9% under 1.5°C to 17% under 2°C in Global Heating. It should be noted that with the current rate of greenhouse gas emissions a global warming of 1.5°C will be reached between 2030 and 2050 instead of the end of the century when it would exceed 3°C.

In a study carried out by Driouech and al. (2013) [21], the average temperatures recorded at different meteorological stations show trends of +0.2°C to +0.3°C per decade over the period 1961-2008. According to the IPCC special report on the 1.5°C warming [22,26], during the decade 2006-2015, the average annual temperatures in Morocco increased from 0.75°C to 2.25°C. In addition, the annual rainfall decreased in different regions of the northern half of Morocco at a rate of 5 mm to 25 mm per decade over the period 1951-2010. Tramblay and al. (2023) [23] also assessed the annual rainfall trends using observations recorded at Moroccan sites located in the extreme north of the country and confirmed these trends.

These results are confirmed by the national meteorological services [24], where the analysis of the change in temperature and rainfall recorded in the various meteorological stations in Morocco between 1961-2017 shows the following statements:

- A significant warming of the annual average temperature during this period (a maximum of 2.6 °C recorded)
- A global trend of increasing annual minimum temperatures.
- A statistically significant rainfall's decrease:
  - rainfall during the extended winter (October-March) of the order of -16%;
  - spring rainfall (March-April-May) reaching -43%;
  - winter rainfall (December-January-February) of around -26%;
  - Annual cumulative rainfall of around -16% over the said period (1961-2017).
- A reduction in the North half of Morocco of the number of days with cumulative rainfall exceeding 10 mm.

The changes in temperature and rainfall induce a negative water balance through the increase in evaporation, this conclusion has been confirmed by various previous studies carried out on a global scale, on the Mediterranean basin or on the African continent [25]. Moreover, this is visibly represented by the decrease in water supply in some regions in Morocco.

The homogenized time series of the Oued El Mahazine dam inflow (1945 to 2016) were analysed with the two applications KhronoStat and XLStat for the detection of the breaking point and trends (Fig.5).

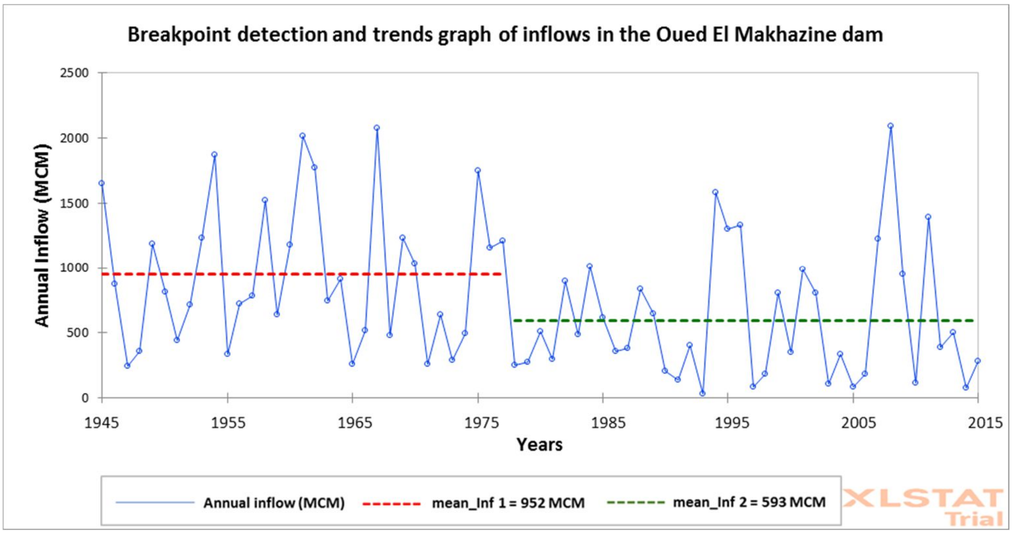


Fig. 5: Breakpoint detection and trends graph of inflows in the Oued El Makhazine dam.

The figure shows the existence of two mean values before and after the break date. A first average of 951.86 MCM/y for the 1945-1978 series before the rupture date and a second average of 592.63 MCM/y for the 1979-2016 series after the rupture date. This break in inputs is justified by a very remarkable and long-lasting decrease in rainfall after 1979. The Mann-Kendall test represents a downward trend in intakes of 12%.

2.3.2 Future projections

According to the 5th report of the IPCC [22,26], the average annual temperatures would increase whatever the scenario. They would be warmer compared to those of 1986-2005 by 2 °C to 3 °C in the current mid-century (2046-2065) and from 3.5 °C to 5.5 °C at the end of the century (2081-2100) under the intense scenario RCP8.5. The future changes in annual rainfall also show, under RCP8.5, a large consensus among models for reductions in the northern half of the country. These declines range from -10% to -20% for the middle of the century and from -15% to more than -25% at the end.

In the northern quarter of Morocco, an analysis carried out by Molinié and al. [27] with very high-resolution models (12 km), shows a decreasing trend in maximum rainfall value in winter and spring. Small negative changes are projected for the autumn. Polade and al. [28] also confirmed the reductions in winter rainfall that varies between 20% and 30% by 2060–2089, compared to the reference period 1960–1989.

According to the IPCC (2014), Jiménez Cisneros and al. (2014) and Schleussner and al. [20,26,29], the Mediterranean region of which Morocco is part will experience an additional disruption of their hydrological cycles over the coming decades, the reduction in water resources availability and a decrease of 10% to 17% depending on the degree of the global warming. For Tramblay and al. [30], the effect of increases in evapotranspiration (+ 10% to + 30%) combined with reductions in rainfall give, under the RCP8.5 scenario, a decline in surface water resources in winter and spring for the basins located in the wetland of North Africa including the Loukkos basin.

According to the previous studies and the results of the dynamic downscaling carried out, at the DMN, using a regional climate model shot at high resolution over Morocco [31], the average temperatures would rise from 1.2 to 2.4 °C by 2050 (2036-2065) depending on the region. The number of heat wave days would increase in general and particularly in the east (+8 to +10 days). Reductions in annual rainfall of 5% to 25% compared to the period 1971-2000 are also projected in conjunction with an increase in drought.

Taking into account the previous studies on trends concerning rainfall over Morocco and the hypotheses of the National water plan project of morocco [17], we assume a reduction of runoff by the mid-term of the 21st century in the area of the future reservoir of about 20% and of 30% by the end of the century.

3 Results and discussion

In this study, the recorded shortage is mainly from the irrigation demand, since the public water demand has the first priority over irrigation and must be satisfied at 100%.

The first simulation of the reference situation (S1) focused on the evaluation of the hydraulic performance of Oued El Makhazine dam. As reported in the table below (Table.3), the results showed that the dam provides a total regularized volume of 309 MCM, 22 MCM for public water supply, guaranteed at 100%, and 287 MCM for irrigation supply with 50 % and a frequency of shortage around 13 %. The supply meet fully the water demands. On the other hand, in many periods the irrigation supply exceed water demand by almost 20% that is not valued and spilled to the sea. In addition, a significant annual volumes recorded are discharged to the sea especially during wet years. Indeed, the maximum spilling is about 1737 MCM/y.

The second scenario (S2) simulate the future situation of the existing hydraulic system, taking into account the dam silting rate at 2050 horizon. The result of the S2 (2.1) scenario showed the vulnerability of the system to satisfy the water irrigation demand, with a maximum shortage recorded around 81% and an average irrigation water supply of 281 MCM. This situation is still more difficult with the integration of climate change impact S2 (2.2), where the average supply will decrease to reach 267 MCM with a shortage frequency of 31% and a maximum shortage of 100%. The admitted shortage criteria is not fullfilled and the water supply does not meet the future irrigation demand. However, a large volume will be spilled to the sea during wet years, with a maximum of 1700 MCM/y and an average exceeding 350 MCM/y. Hence, it is mandatory to have an additional storage capacity to benefit from this water loss in times of drought and to minimize flooding downstream of the dam.

The third scenario (S3) includes the construction of the Tfer dam upstream the Oued El Makhazine dam for better mobilization of water resources in the Loukkos basin. The simulations results S3(3.1) show that with the construction of the Tfer dam, the Oued El Makhazine dam will regulate a maximum water irrigation supply of 375 Mm^3/y, with an increase in irrigation water supply compared to the demand by 20% while respecting the admitted shortage criteria. The results of the scenario that includes climate change impact S3(3.2) showed a decrease of around 15% in water irrigation supply compared to the previous scenario. The average supply is around 333 MCM/y, which remains higher than the future demand, and the Oued El Makhazine - Tfer hydraulic complex will be able to meet water needs by 2050. In addition, spilling will decrease to reach an average of 130 MCM/y and a maximum of 850 MCM/y, with a 50% reduction compared to the first two scenarios.

Table 3. Summary of simulations result for the scenarios SI, SII, and SIII.

	Scenario I (S1)		**Scenario II (S2.1)**		**Scenario II (S2.2)**		**Scenario III (S3.1)**		**Scenario III (S3.2)**	
Water demand (MCM)	**242**	**22**	**312**	**34**	**312**	**34**	**312**	**34**	**312**	**34**
Called demand (MCM)	**287**	**22**	**312**	**34**	**312**	**34**	**375**	**34**	**333**	**34**
Average supply (MCM)	280	22	281	34	267	34	363	34	311	34
Minimum supply (MCM)	143	22	59	34	0	34	180	34	166	34
Frequency of deficiency %	13	0	22	0	31	0	15	0	14	0
Maximum deficit %	50	0	**81**	0	**100**	0	50	0	50	0

4 Conclusion

This article aims to study the potentials of hydrological modeling to reproduce the hydrological cycle and assess the impact of climate change on the mobilization of water resources in the basin. Indeed, this approach focuses on strengthening the water supply system by 2050, by increasing the storage capacity, which will improve the water regulation of the Loukkos basin.

According to the main results of this study, Oued El Makhazine dam cannot satisfy the water demand until 2050. Therefore, by 2050, the irrigation water supply will not meet the irrigation water demand, and this supply will be reduced with the effect of climate change. However, large volumes of water will be lost at sea and not valuable. This is mainly due to the low storage capacity at the Oued El Makhazine dam, which continues to decrease under the effect of siltation of the reservoir.

The solution of building a Tfer dam immediately upstream of the Oued El Makhazine dam will improve the irrigation water supply by 20% and reduce the volumes of discharged water to sea by up to 50%.

The decision-makers should continue their efforts in water resources management to anticipate deficits in water supplies. Moreover, to provide an efficient system, other alternative of integrated water resources management in the Loukkos basin can be studied, as the inter-basin transfer between the Loukkos basin and another deficit basin.

The objective of these transfer projects is to balance the storage capacities in the different basins and to manage the dam reservoirs in an integrated way. This project aims to minimize water losses and to reduce the gap of deficits between water supply and demand and improve resilience under climate change impact.

In our case, the water losses can be valued by its use in the adjacent basin “Tangérois”. This basin suffers from enormous deficits in drinking water supply during the succession of years of drought.

The possibility of realizing a transfer project between these two basins will be examined as part of another work, where we will try to determine the management rules between the different hydraulic systems, the transferable water volumes and water allocation priorities without compromising the water uses of the emitting basin.

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